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Jennifer G. Duan

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14. ABSTRACT

The objective is to study turbulent flow and sediment transport near dike structures of various geometries through an integrated laboratory experimental, numerical modeling, and field application. Major accomplishment includes: 1) developed a two-dimensional depth-averaged hydrodynamic model to simulate the evolution of meandering channels from the complex interaction between downstream and secondary flows, bed load and suspended sediment transport, and bank erosion. The model correctly replicates the different phases of the evolution of free

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Report Title

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ABSTRACT

The objective is to study turbulent flow and sediment transport near dike structures of various geometries through an integrated laboratory experimental, numerical modeling, and field application. Major accomplishment includes: 1) developed a two-dimensional depth-averaged hydrodynamic model to simulate the evolution of meandering channels from the complex interaction between downstream and secondary flows, bed load and suspended sediment transport, and bank erosion. The model correctly replicates the different phases of the evolution of free meandering channels in experimental laboratory settings, such as downstream and upstream migration, lateral extension, and rotation of meander bends; 2) developed a three-dimensional model and simulated flow field around the experimental dikes. Experimental data from the laboratory study of flow in a flat bed and scoured bed around a series of three dikes were used to verify the results from the numerical model; 3) evaluated 31 commonly used formulae for predicting the total sediment load. This study attributed these deviations to the stochastic properties of bed shear stresses due to varying flow field and sediment sizes. Seven papers have been submitted to peer-reviewed journals, among them, four have been published. One Ph.D. and one MS degree are awarded to graduate students, and four high-school students are trained as summer interns.

Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in non peer-reviewed journals:

(c) Presentations

Duan, J. G., Julien, P., Zhang, S. Y., and Acharya, A. (2009) Numerical Simulation of meandering Evolution Processes, AGU Conference, San Francisco.

Yaeger M., and Duan J. G. (2008) Comparison of Mean Flow and Turbulence around Series of Experimental Dikes, AGU Conference, San Francisco.

Acharya, A., and Duan J. G. (2008) Statistical Properties of Total Sediment Transport Formulas, AGU Conference, San Francisco.

Duan, J. G., and He, L. (2008) Turbulent Bursts around Experiment Spur Dikes, AGU Conference, San Francisco.

Number of Presentations: 4.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

(d) Manuscripts

Received Paper

TOTAL:

Number of Manuscripts:

Books

Received Paper

TOTAL:

Patents Submitted

Patents Awarded

Awards

- NSF Career Award – this award is the most prestigious NSF award to junior faculty.
- Diplomate, American Academy of Water Resource Engineers —The PI was recognized as diplomate of American Academy of Water Resource Engineers. The membership is given to senior water resource engineers to recognize their accomplishments.
- Arizona Floodplain Management Scholarship—One graduate student (Mary Yeager) working on the project received the Arizona Floodplain Management Scholarship ($2000), which is to award outstanding graduate students in the area of water resource and floodplain management.
- 3rd Place Research Poster Competition – One graduate student (Anu Acharya) received 3rd award in the Annual Arizona Water Sustainability Conference in 2010. Her poster title is "Experimental and Numerical Modeling Study of Local Scour Near Three Series of Dikes".

Graduate Students

NAME	PERCENT_SUPPORTED	Discipline
Mary Yaeger	1.00	
Anu Acharya	1.00	
FTE Equivalent:	**2.00**	
Total Number:	**2**	

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Faculty Supported

NAME	PERCENT_SUPPORTED	National Academy Member
Jennifer Duan	0.20	
FTE Equivalent:	**0.20**	
Total Number:	**1**	

Names of Under Graduate students supported

NAME	PERCENT SUPPORTED	Discipline
Marika Klappert	0.33	Civil Engineering
Ramsey Conorade	0.10	Natural Resource
Ruy Bautista	0.20	Mathematics
FTE Equivalent:	**0.63**	
Total Number:	**3**	

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period:	3.00
The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:.....	3.00
The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:.....	1.00
Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):	2.00
Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:	0.00
The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense	3.00
The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields:	1.00

Names of Personnel receiving masters degrees

NAME
Mary Yaeger
Total Number: 1

Names of personnel receiving PHDs

NAME
Anu Acharya
Total Number: 1

Names of other research staff

NAME	PERCENT SUPPORTED
Steve Albanses	0.10
FTE Equivalent:	**0.10**
Total Number:	**1**

Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

Technology Transfer

Final Report

Project Title

IMPACT OF DIKE STRUCTURES ON SEDIMENT TRANSPORT IN THE ALLUVIAL RIVERS

Proposal Number: 52326EV

Contract Number: W911NF-07-1-0412

Principal Investigator

Guohong (Jennifer) Duan, Ph.D., P.E.

Associate Professor

Department of Civil Engineering and Engineering Mechanics

The University of Arizona

September 5th, 2012

ABSTRACT

The objective is to study turbulent flow and sediment transport near dike structures of various geometries through an integrated laboratory experimental, numerical modeling, and field application. Major accomplishment includes: 1) developed a two-dimensional depth-averaged hydrodynamic model to simulate the evolution of meandering channels from the complex interaction between downstream and secondary flows, bed load and suspended sediment transport, and bank erosion. The model correctly replicates the different phases of the evolution of free meandering channels in experimental laboratory settings, such as downstream and upstream migration, lateral extension, and rotation of meander bends; 2) developed a three-dimensional model and simulated flow field around the experimental dikes. Experimental data from the laboratory study of flow in a flat bed and scoured bed around a series of three dikes were used to verify the results from the numerical model; 3) evaluated 31 commonly used formulae for predicting the total sediment load. This study attributed these deviations to the stochastic properties of bed shear stresses due to varying flow field and sediment sizes. Seven papers have been submitted to peer-reviewed journals, among them, four have been published. One Ph.D. and one MS degree are awarded to graduate students, and four high-school students are trained as summer interns.

TABLE OF CONTENTS

OBJECTIVES

The project has two components: one is to apply a computational model (EnSed2D) into a practical river engineering project in the Mississippi River, and the other is to collect laboratory experimental data for model verification, and to perform risk and uncertainty analysis of modeling results to explore uncertain parameters affecting the predictions. In particular, this project aims to conduct laboratory experiments of flow hydrodynamic and sediment transport around dikes. Flow and sediment transport field around the dikes of various alignments (e.g. angled, perpendicular, submerged, or emerged) will be measured in a series of experiments. These measured data will be used to verify the numerical model, and examine how dike structures of various alignments affect or improve water environments for in-stream habitat.

APPROACH

The proposed project consists of three parts: 1) conducting laboratory experiments to develop data for model verifications; 2) applying the EnSed2D model to the field site for evaluating the effectiveness of various design alternatives; 3) performing risk and uncertainty analysis of the modeling results to support management decisions. The objective is to study turbulent flow and sediment transport near dike structures of various geometries through an integrated laboratory experimental, numerical modeling, and field application. The result will be a feasible design of dike structures that can effectively reduce sediment deposition and maintain a favorable flow condition during winter low flows in the island. The risk and uncertainty of the selected design will be analyzed using the Monte Carlo simulation.

SIGNIFICANCE AND ARMY VALUE

The proposed research is significant: (1) using a practical engineering project as the objective to formulate research plans; (2) linking numerical models with laboratory experiments to enhance model's capabilities; (3) conducting risk and uncertainty analysis of numerical models for better decision making; and (4) increasing the visibility of women and minorities in engineering and sciences through educating and training women graduate and undergraduate students from the University of Arizona.

On a broader scale, this project demonstrated that the research product from an ARO funded project is a cost-effective tool for analyzing engineering alternatives for river management. The expected experimental and modeling results should provide useful insight into the management of flow and sediment in the Mississippi River, which is vital to preserve the integrity of ecosystem (Fig.1). In addition, the proposed study will provide valuable continuity with research previously funded by the Army Research Office to enhance sediment transport modeling in order to predict morphodynamic processes. The dataset will be disseminated through publications and the ASCE Task Committee on Computational Modeling of Sediment Transport Processes, where Dr. Duan serves as the committee chair of this committee.

HIGHLIGHTS OF ACCOMPLISHMENTS

1. A two-dimensional depth-averaged hydrodynamic model is developed to simulate the evolution of meandering channels from the complex interaction between downstream and secondary flows, bed load and suspended sediment transport, and bank erosion. The depth-averaged model calculates both bed load and suspended load assuming equilibrium sediment transport and simulates bank erosion with a combination of two interactive processes: basal erosion and bank failure. The model correctly replicates the different phases of the evolution of free meandering channels in experimental laboratory settings including: (1) downstream and upstream migration; (2) lateral extension; and (3) rotation of meander bends (Fig.1).

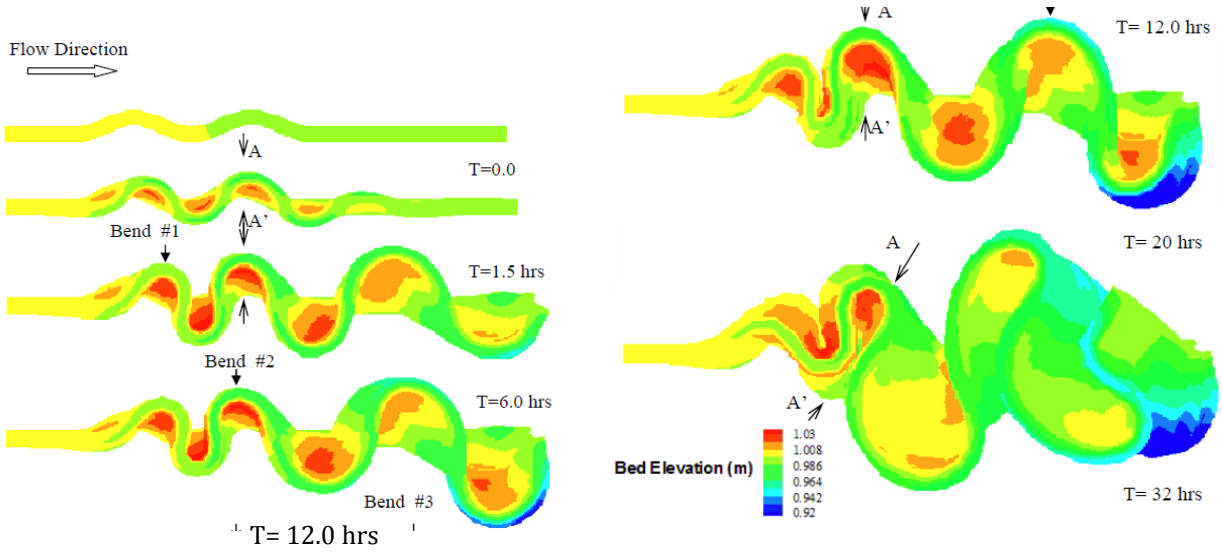

Fig.1. Numerical simulation of the topographic evolution of a meandering channel

Note: This figure shows the evolution of a meandering stream from low to high sinuosity. The yellow/orange/red colored area are sand bars, while the blue/green colored areas are pools and flow area. This result showed that meandering migration is caused by the imbalance of sediment transport between the inner and outer banks that drives the meandering loop expand, rotate, and migrate.

2. Developed a three-dimensional model and simulated flow field around the experimental dikes. Experimental data from the laboratory study of flow in a flat bed and scoured bed around a series of three dikes were used to verify the results from the numerical model. Modeling results of turbulent kinetic energy using the standard $k-\varepsilon$ model showed over 50% discrepancy from the measured. The RNG $k-\varepsilon$ model yielded better results of both mean flow field and turbulence kinetic energy for the flat bed surface and scoured bed surface. Based on these results, this study recommends the use of RNG $k-\varepsilon$ model for simulating mean flow field around dikes (Fig.2).

Fig.2a
Dikes in Mississippi River

Fig.2b Picture of scoured bed

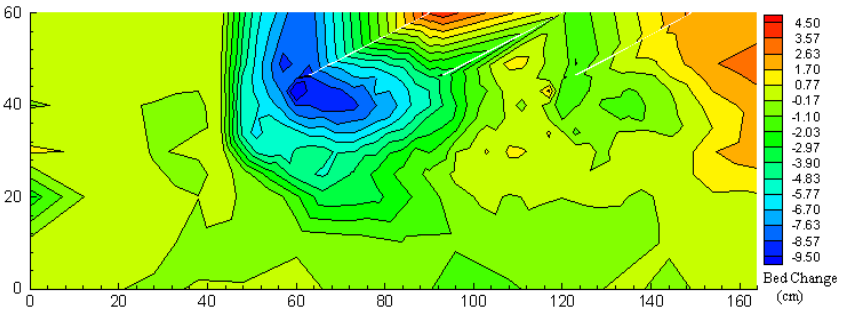

Fig.2c Bed bathymetry of the developed scour hole at Q = 0.035 m^3/s

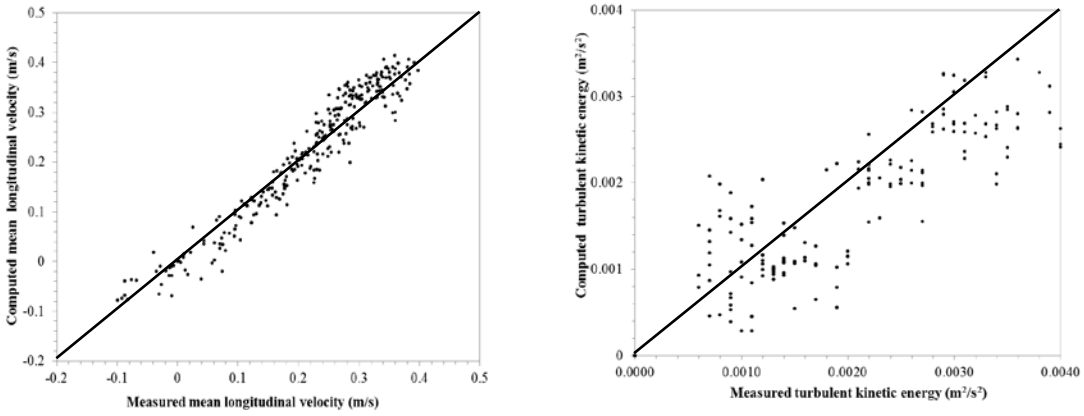

Fig.2d Comparison of simulated and measured mean and turbulence flow properties

Fig.2. Measured and simulated three-dimensional mean and turbulence flow field
Note: Fig.2a is a series of dikes in the Mississippi River. Fig.2b is the experimental results of local scour near dikes. Fig.2c is the measured bathymetry plotted in shaded color. Fig.2d compared the experimental measurements of mean flow velocity and turbulent kinetic energy with the simulated results from FLOW3D model. This result implies that 3D hydrodynamic model is capable of simulating local scour and turbulence flow near dikes.

3. This study evaluated 31 commonly used formulae for predicting the total sediment load. It's well known, at a given flow and sediment condition, the results from these formulae deviate significantly from each other. This study attributed these deviations to the stochastic properties of bed shear stresses due to varying flow field and sediment sizes. The Monte Carlo simulation was applied to each equation by assuming the bed shear stress obeys the log-normal distribution. A unified total sediment load equation is obtained based on the mean value from all the equations. The results showed the mean of all the equations is a power function of dimensionless bed shear stress. 6,999 sets of laboratory and field data were used to verify this newly derived equation.

TECHNOLOGY TRANSFER

- Visit Vicksburg Mississippi in August 2010, and attended the annual program review. During the meeting period, the PI visited the Environmental Laboratory at ERDC, and talked about collaborations in using 2D model for study the wetland in Louisiana estuarine area.

- Collaborate with environmental scientists, Dr. Zhonglong Zhang and Dr. Billy Johnson, and co-developed a pre-proposal to DOD Strategic Environmental Research and Development Program. The pre-proposal was invited for a full proposal submission in March 2011. .

- The PI also meets with Lisa Hubbard, Chief of River Sedimentation Branch in Coastal and Hydraulics Lab. in 2010 and discussed about use the application of ROMS model to simulate coastal processes in Florida. DR. Hubbard is helping PI to acquire bathymetry data from Corps of Engineers' Mobile District.

EDUCATION AND TRAINING

This project provided financial support to two graduate students and four high school interns. One graduate student, *Mary Yaeger*, graduated in May 2009 (currently, Ph.D. student at the Department of Civil and Environmental Engineering at Univ. of Illinois, Urbana-Champaign), and one Ph.D. student, *Anu Acharya*, graduated in Jan 2011 (currently, Surface Water Hydrologist at Arcadis US, Inc, Boulder, CO, an international civil engineering consulting company). Four high school interns: *Alex Jacob* (currently, freshman studying mathematics at Univ. of Chicago), *Timothy Gort* (currently, freshman studying geology and mining engineering at Colorado School of Mines, Boulder, CO), *Will Ramos* (currently, senior, Paseo Verde Highs School, Tucson, AZ), *Wendy Wang* (currently, sophomore, Foothill High School, Tucson, AZ).

PUBLICATION

Referred Papers in Peer Reviewed Journals (see Appendix):

Duan, J. G., and Julien, P. Y. (2010). "Numerical simulation of meandering evolution." *J. Hydrol.*, doi:10.1016/j.jhydrol.2010.07.005.

Duan, J. G., and He, L., Fu, X.D., Wang G. X. (2009). "Mean flow and turbulence around experimental spur dike." *Advances in Water Resources, Vol. 32(12), 1717-1725.*

Duan, J. G. (2009). "Mean flow and turbulence around a laboratory spur dike." *J. Hydraul. Eng.*, 135(10), 803-811.

Duan, J. G., He, L., Wang, G. Q. and Fu, X. D. (2011), "Turbulent bursts around an experimental spur dike." *International J. of Sediment Res.*, Vol 26, No. 4, 471-486.

Duan, J. G.**,** Yaeger, M., and Acharya, A., Distribution of bed shear stress around series of straight and angled **dikes, *International J. of Sediment Res.*, in review**.

Acharya, A. and Duan, J. G., A unified total sediment load formula, *J. Hydrol.*, **in revision.**

Acharya, A. and Duan, J. G., "Three dimensional simulation of flow field around series of spur dikes," *Computer and Geoscience Journal.*, in **revision**.

Referred Papers in Conference Proceedings:

Acharya, A. and Duan, J.G. "Three dimensional simulation of flow around series of spur dikes." ASCE Conf. Proc. doi:10.1061/41173(414)218 ASCE EWRI World Water Congress 2011.

Yaeger, M. and Duan, J. G. (2010). "Mean flow and turbulence around two series of experimental dikes." *ASCE Conf. Proc.* 371, 178, DOI: 10.1061/41114(371)178.

Duan,J. G., He, L., Wang, G. Q., and Fu, X. D. (2010). "Turbulent burst around experimental spur dike." *ASCE Conf. Proc.* 371, 179, DOI: 10.1061/41114(371)179

Duan, J. G., and He, L. (2009). "Comparison of mean flow and turbulence around experimental spur dike." *ASCE Conf. Proc. 342*, 302, DOI: 10.1061/41036(342)302.

Duan, J. G., Acharya, A., Yaeger, M., and Zhang, S. Y. (2008). "Evaluation of flow and sediment models for the Rillito River." *ASCE Conf. Proc. 316*, 228, DOI: 10.1061/40976(316)228.

Duan, J. G., Acharya, A., and Yeager, M. (2008). "Sediment sorting around experimental spur dike." *ASCE Conf. Proc. 316*, 231 (2008), DOI: 10.1061/40976(316)231.

AWARDS/HONORS RECEIVED IN 2008-2011

- NSF Career Award – this award is the most prestigious NSF award to junior faculty.
- Diplomate, American Academy of Water Resource Engineers —The PI was recognized as diplomate of American Academy of Water Resource Engineers. The membership is given to senior water resource engineers to recognize their accomplishments.
- Arizona Floodplain Management Scholarship—One graduate student (Mary Yeager) working on the project received the Arizona Floodplain Management Scholarship ($2000), which is to award outstanding graduate students in the area of water resource and floodplain management.
- 3rd Place Research Poster Competition – One graduate student (Anu Acharya) received 3rd award in the Annual Arizona Water Sustainability Conference in 2010. Her poster title is "Experimental and Numerical Modeling Study of Local Scour Near Three Series of Dikes".

APPENDIX:

PAPERS PUBLISHED /SUBMITTED TO PEER-REVIEWED JOURNALS